5.0 TEMPERATURE

5.1 Summary

During the 1998 SWQB sampling monitoring effort in the Upper Rio Chama Watershed, thermograph data recorded several exceedences of the New Mexico water quality standard for temperature throughout the watershed. Thermographs were set to record every 15 minutes for several weeks to months during the warmest time of the year (generally June through September). Thermograph data are assessed using the SWQB/NMED temperature protocol (SWQB/NMED 2001b). Rio Chamita, Rio Chama, Chavez Creek, Rio Brazos, and Rito de Tierra Amarilla were listed on the 2000-2002 Clean Water Act §303(d) list for temperature. A TMDL for temperature was previously completed for Rio Chamita (SWQB/NMED 1999b).

5.2 Endpoint Identification

Target Loading Capacity

Target values for these temperature TMDLs will be determined based on 1) the presence of numeric criteria, 2) the degree of experience in applying the indicator, and 3) the ability to easily monitor and produce quantifiable and reproducible results. For this TMDL document, target values for temperature are based on the reduction in solar radiation necessary to achieve numeric criteria as predicted by a temperature model. This TMDL is also consistent with New Mexico's antidegradation policy.

The New Mexico WQCC has adopted numeric water quality criteria for temperature to protect the designated use of HQCWF (20.6.4.900.C NMAC). These water quality standards have been set at a level to protect cold-water aquatic life such as trout. The HQCWF use designation requires that a stream reach must have water quality, streambed characteristics, and other attributes of habitat sufficient to protect and maintain a propagating coldwater fishery (i.e., a population of reproducing salmonids). The primary standard leading to an assessment of use impairment is the numeric criterion for temperature of 20 °C (68°F). The following TMDLs address the following reaches where temperatures exceeded the criterion (see Appendix D for graphical representation of thermograph data):

> RIO CHAMA -- Two thermographs were deployed on this reach in 1998. The upper thermograph was deployed under the HWY 17 bridge (SWQB station 8) and did not exceed the HQCWF criterion. The lower thermograph was deployed at the Rio Chama and Hwy 84 fishing access (SWQB station 9). Recorded temperatures exceeded the HQCWF criterion 363 of 1,704 times with a maximum temperature of 26°C. In 2002, a thermograph was deployed in the Rio Chama at under HWY 95 bridge immediately downstream of the listed reach for verification and model calibration purposes. Recorded temperatures exceeded the HQCWF criterion 912 of 2616 times with a maximum temperature of 27.9°C. A thermograph re-deployed at station 9 was destroyed either by vandals or while an in-channel irrigation diversion was being constructed.

CHAVEZ CREEK -- In 1998, one thermograph was deployed on Chavez Creek at the County RD 512 bridge (SWQB station 13). Recorded temperatures exceeded the HQCWF criterion 160 of 864 times with a maximum temperature of 26°C. In 2002, a thermograph was re-deployed at this location for verification and model calibration purposes. Recorded temperatures exceeded the HQCWF criterion 371 of 2616 times with a maximum temperature of 28.7°C.

RIO BRAZOS -- Two thermographs were deployed on this reach in 1998. The upper thermograph was deployed above Corkin's Lodge (SWQB station 12) and did not exceed the HQCWF criterion. The lower thermograph was deployed at the Rio Brazos and Hwy 84 bridge (SWQB station 14). Recorded temperatures exceeded the HQCWF criterion 463 of 1,752 times with a maximum temperature of 27°C. In 2002, a thermograph was re-deployed at this location for verification and model calibration purposes. Recorded temperatures exceeded the HQCWF criterion 944 of 2586 times with a maximum temperature of 29.2°C. An additional thermograph was deployed in the Rio Brazos at County Road 162 near the upstream end of the listed reach for verification and model calibration purposes.

RITO DE TIERRA AMARILLA -- Two thermographs were deployed on this reach in 1998. The upper thermograph was deployed at the HWY 64 bridge (SWQB station 15) and did not exceed the HQCWF criterion. The lower thermograph was deployed on the Rito de Tierra Amarilla at the Hwy 112 bridge (SWQB station 16) and exceeded the HQCWF criterion 194 of 864 times with a maximum temperature of 29.5°C. In 2002, a thermograph was re-deployed at the upper station location for verification and model calibration purposes. Recorded temperatures did not exceed the HQCWF criterion. It was not possible to re-deploy a thermograph at the lower station because channel flow was reduced to standing pools during the summer months in 2002.

Calculations

The Stream Segment Temperature (SSTEMP) version 2.0 was used to predict stream temperatures based on watershed geometry, hydrology, and meteorology. This model was developed by the USGS Biological Resource Division (Bartholow 2002). The model predicts minimum 24-hour temperatures, mean 24-hour temperatures, and maximum 24-hour stream temperatures for a given day, as well as a variety of intermediate values. The predicted temperature values are compared to actual thermograph readings measured in the field in order to calibrate the model. The SSTEMP model identifies current stream and/or watershed characteristics that control stream temperatures. The model also quantifies the maximum loading capacity of the stream to meet water quality criteria for temperature. This model is important for estimating the effect of changing controls or factors (such as riparian grazing, stream channel alteration, and reduced streamflow) on stream temperature. The model can also be used to help identify possible implementation activities to improve stream temperature by targeting those factors causing impairment to the stream.

Waste Load Allocations and Load Allocations

•Waste Load Allocation
There are no point source contributions associated with this TMDL. The waste load allocation (WLA) is zero.

•Load Allocation
Water temperature can be expressed as heat energy per unit volume. SSTEMP provides an estimate of heat energy per unit volume expressed in joules (the absolute meter kilogram-second unit of work or energy equal to 10^7 ergs or approximately 0.7375 foot pounds) per meter squared per second ($j/m^2/s$) and Langley's (a unit of solar radiation equivalent to one gram calorie per square centimeter of irradiated surface) per day. The following information relevant to the model runs used to determine temperature these TMDLs was copied from the user's manual (Bartholow 2002). Please refer directly to the user's manual for the complete text. Various notes have been added in parentheses to clarify local sources of input data.

DESCRIPTION OF LOGIC

SSTEMP version 2.0 integrates SSSOLAR version 1.6 and SSSHADE version 1.4 into one simple-to-use program. In general terms, SSTEMP calculates the heat gained or lost from a parcel of water as it passes through a stream segment. This is accomplished by simulating the various heat flux processes that determine temperature change. These physical processes include convection, conduction, evaporation, as well as heat to or from the air (long wave radiation), direct solar radiation (short wave), and radiation back from the water. SSTEMP first calculates the solar radiation and how much is intercepted by (optional) shading. This is followed by calculations of the remaining heat flux components for the stream segment. The details are just that: To calculate solar radiation, SSTEMP computes the radiation at the outer edge of the earth's atmosphere. This radiation is passed through the attenuating effects of the atmosphere and finally reflects off the water's surface depending on the angle of the sun. For shading, SSTEMP computes the day length for the level plain case, i.e., as if there were no local topographic influence. Next the local topography is factored in by computing the sunrise and sunset times based on the east and west-side topography. Thus, the local topography results in a percentage decrease in the level plain daylight hours. From this local sunrise/sunset, the program computes the percentage of light that is filtered out from the riparian vegetation. This filtering is the result of the size, position and density of the shadow-casting vegetation on both sides of the stream.

HYDROLOGY PARAMETERS

1. **Segment Inflow (cfs or cms)** -- Enter the mean daily flow at the top of the stream segment. If the segment begins at an effective headwater, the flow may be entered as zero; all accumulated flow will accrue from lateral inflow, both surface and groundwater.

If the segment begins at a reservoir, the flow will be the outflow from that reservoir. Remember that this model assumes steady-state flow conditions.

2. **Inflow Temperature (°F or °C)** -- Enter the mean daily water temperature at the top of the segment. If the segment begins at a true headwater, you may enter any water temperature, because zero flow has zero heat. If there is a reservoir at the inflow, use the reservoir release temperature. Otherwise, use the outflow from the upstream segment. [NOTE: Thermograph data from the top of the modeled reach is used to determine the inflow temperature.]

3. **Segment Outflow (cfs or cms)** -- The program calculates the lateral discharge by knowing the flow at the head and tail of the segment, subtracting to obtain the net difference, and dividing by segment length. The program assumes that lateral inflow (or outflow) is uniformly apportioned through the length of the segment. If any "major" tributaries enter the segment, you probably should divide the segment into two or more subsections. "Major" is defined as any stream contributing greater than 10% of the mainstem flow.
[NOTE: To be conservative, 4Q3 low flow values were used as the segment outflow. These critical low flows were used to decrease assimilative capacity of the stream to adsorb and disperse solar energy. See Appendix E for calculations.]

4. **Accretion Temperature (°F or °C)** -- The temperature of the lateral inflow, barring tributaries, generally should be the same as groundwater temperature. In turn, groundwater temperature may be approximated by the mean annual air temperature. You can verify this by checking United States Geological Survey (USGS) well log temperatures. Exceptions may arise in areas of geothermal activity. If irrigation return flow makes up most of the lateral flow, it may be warmer than mean annual air temperature. Return flow may be approximated by equilibrium temperatures.
[NOTE: Mean annual air temperature data are found at the Western Regional Climate Center web site (www.wrcc.dri.edu).]

GEOMETRY PARAMETERS

1. **Latitude (decimal degrees or radians)** -- Latitude refers to the position of the stream segment on the earth's surface. It may be read off of any standard topographic map.
[NOTE: Latitude is generally determined in the field with a GPS unit.]

2. **Dam at Head of Segment (checked or unchecked)** -- If there is a dam at the upstream end of the segment with a constant, or nearly constant diel release temperature, check the box, otherwise leave it unchecked…Maximum daily water temperature is calculated by following a water column from solar noon to the end of the segment, allowing it to heat up towards the maximum equilibrium temperature. If there is an upstream dam within a half-day's travel time from the end of the segment, a parcel of water should only be allowed to heat for a shorter time/distance.

3. **Segment Length (miles or kilometers)** -- Enter the length of the segment for which you want to predict the outflowing temperature. Remember that all parameters will be assumed to remain constant for the entire segment. Length may be estimated from a topographic map, but a true measurement is best.
[NOTE: Segment length is determined with National Hydrographic Dataset Reach Indexing GIS tool.]

4. **Upstream Elevation (feet or meters)** -- Enter elevation as taken from a 7 ½ minute quadrangle map.
[NOTE: Upstream elevation is generally determined in the field with a GPS unit.]

5. **Downstream Elevation (feet or meters)** -- Enter elevation as taken from a 7 ½ minute quadrangle map. Do not enter a downstream elevation that is higher than the upstream elevation.
[NOTE: Downstream elevation is generally determined in the field with a GPS unit.]

6. **Width's A Term (seconds/foot^2 or seconds/meter^2)** -- This parameter may be derived by calculating the wetted width-discharge relationship… To conceptualize this, plot the width of the segment on the Y-axis and discharge on the X-axis of log-log paper…The relationship should approximate a straight line, the slope of which is the B term (the next parameter). Theoretically, the A term is the Y-intercept. However, the width vs. discharge relationship tends to break down at very low flows. Thus, it is best to calculate B as the slope and then solve for A in the equation:

$W = A * Q^B$
where:
Q is a known discharge
W is a known width
B is the power relationship

Regression analysis also may be used to develop this relationship. First transform the flow to natural log (flow) and width to natural log (width). Log (width) will be the dependent variable. The resulting X coefficient will be the B term and the (non-zero) constant will be the A term when exponentiated. That is:

A = e^constant from regression
where ^ represents exponentiation

As you can see from the width equation, width equals A if B is zero. Thus, substitution of the stream's actual wetted width for the A term will result if the B term is equal to zero. This is satisfactory if you will not be varying the flow, and thus the stream width, very much in your simulations. If, however, you will be changing the flow by a factor of 10 or so, you should go to the trouble of calculating the A and B terms more precisely. Width can be a sensitive factor under many circumstances.
[NOTE: After Width's B Term is determined (see note below), Width's A Term is calculated as displayed above.]

7. **Width's B Term (essentially dimensionless)** -- From the above discussion, you can see how to calculate the B term from the log-log plot. This plot may be in either English or international units. The B term is calculated by linear measurements from this plot. Leopold et al. (1964, p.244) report a variety of B values from around the world. A good default in the absence of anything better is 0.20; you may then calculate A if you know the width at a particular flow.
[NOTE: Width's B Term is calculated at the slope of the regression of the natural log of width and the natural log of flow. Width vs. flow data sets are determined by entering cross-section field data into WINXSPRO (USFS 1998). See Appendix E for details.]

8. **Manning's n (essentially dimensionless**) -- Manning's n is an empirical measure of the segment's "roughness." A generally acceptable default value is 0.035. This parameter is necessary only if you are interested in predicting the minimum and maximum daily fluctuation in temperatures. It is not used in the prediction of the mean daily water temperature.
[NOTE: Rosgen stream type is also taken into account when estimating Manning's n (Rosgen 1996).]

TIME OF YEAR

Month/Day (mm/dd) -- Enter the number of the month and day to be modeled. January is month 01, etc. This program's output is for a single day. To compute an average value for a longer period (up to one month), simply use the middle day of that period. The error encountered in so doing will usually be minimal. Note that any month in SSTEMP can contain 31 days.

METEOROLOGICAL PARAMETERS

1. **Air Temperature (°F or °C)** -- Enter the mean daily air temperature. This information may be measured (in the shade), and should be for truly accurate results; however, this and the other meteorological parameters may come from the Local Climatological Data (LCD) reports which can be obtained from the National Oceanic and Atmospheric Administration for a weather station near your site. The LCD Annual Summary contains monthly values, whereas the Monthly Summary contains daily values.

Use the adiabatic lapse rate to correct for elevational differences from the meteorological station:

$$Ta = To + Ct * (Z - Zo)$$

where:
Ta = air temperature at elevation E (°C)
To = air temperature at elevation Eo (°C)
Z = mean elevation of segment (m)
Zo = elevation of station (m)
Ct = moist-air adiabatic lapse rate (-0.00656 °C/m)

NOTE: Air temperature will usually be the single most important factor in determining water temperature.
[NOTE: Mean daily air temperature data are found at the Western Regional Climate Center web site (www.wrcc.dri.edu) or determined from air thermographs deployed in the shade near the instream thermograph locations. Regardless of the source, air temperatures are corrected for elevation using the above equation.]

2. **Maximum Air Temperature (°F or °C)** -- The maximum air temperature is a special case of an override condition. Unlike the other parameters where simply typing a value influences which parameters "take effect", the maximum daily air temperature overrides only if the check box is checked. If the box is not checked, the program continues to estimate the maximum daily air temperature from a set of empirical coefficients (Theurer et al. 1984) and will print the result in the grayed data entry box. You cannot enter a value in that box unless the box is checked. Note: maximum air temperature appears in the Intermediate Values portion of the screen, not with the other mean daily meteorology values.

3. **Relative Humidity (percent)** -- Obtain the mean daily relative humidity for your area by measurement or from LCD reports by averaging the four daily values given in the report. Correct for elevational differences by:

$$Rh = Ro * [1.0640 \wedge (To-Ta)] * [(Ta+273.16)/(To+273.16)]$$

where:
Rh = relative humidity for temperature Ta (decimal)
Ro = relative humidity at station (decimal)
Ta = air temperature at segment (°C)
To = air temperature at station (°C)
^ = exponentiation

[NOTE: Relative humidity data are found at the Western Regional Climate Center web site (www.wrcc.dri.edu) or National Renewable Energy Laboratory (NREL) Solar Radiation Data Base web site (rredc.nrel.gov/solar/pubs/NSRDB). Regardless of the source, relative humidity data are corrected for elevation and temperature using the above equation.]

4. **Wind Speed (miles per hour or meters/second)** -- Obtainable from LCD reports. Wind speed also may be useful in calibrating the program to known outflow temperatures by varying it within some reasonable range. In the best of all worlds, SSTEMP would like wind speed to be right above the water's surface.
[NOTE: Wind speed data are found at the Western Regional Climate Center web site (www.wrcc.dri.edu) or NREL Solar Radiation Data Base web site (rredc.nrel.gov/solar/pubs/NSRDB).]

5. **Ground Temperature (°F or °C)** -- Use mean annual air temperature from LCD reports.
[NOTE: Mean annual air temperature is found at the Western Regional Climate Center web site (www.wrcc.dri.edu).]

6. **Thermal Gradient (Joules/Meter^2/Second/°C)** -- This elusive quantity is a measure of rate of thermal input (or outgo) from the streambed to the water. It is not a particularly sensitive parameter within a narrow range. This parameter may prove useful in calibration, particularly for the maximum temperature of small, shallow streams where it may be expected that surface waters interact with either the streambed or subsurface flows. In the absence of anything better, simply use the 1.65 default. Note that this parameter is measured in the same units regardless of the system of measurement used.

7. **Possible Sun (percent)** -- This parameter is an indirect measure of cloud cover. Measure with a pyrometer or use LCD Reports.
[NOTE: Percent possible sun is found at the Western Regional Climate Center web site (www.wrcc.dri.edu).]

8. **Dust Coefficient (dimensionless)** -- This value represents the amount of dust in the air. If you enter a value for the dust coefficient, SSTEMP will calculate the solar radiation. Representative values look like the following (TVA 1972):

Winter	6 to 13
Spring	5 to 13
Summer	3 to 10
Fall	4 to 11

If all other parameters are known for a given event, the dust coefficient may be calibrated by using known ground-level solar radiation data.

9. **Ground Reflectivity (percent)** -- The ground reflectivity is a measure of the amount of short-wave radiation reflected back from the earth into the atmosphere. If you enter a value for the ground reflectivity, SSTEMP will calculate the solar radiation.

Representative values look like the following (TVA 1972, Gray 1970):

Meadows and fields	14
Leaf and needle forest	5 to 20
Dark, extended mixed forest	4 to 5
Heath	10
Flat ground, grass covered	15 to 33
Flat ground, rock	12 to 15
Flat ground, tilled soil	15 to 30
Sand	10 to 20
Vegetation, early summer	19
Vegetation, late summer	29
Fresh snow	80 to 90
Old snow	60 to 80
Melting snow	40 to 60

Ice	40 to 50
Water	5 to 15

10. Solar Radiation (Langley's/day or Joules/meter^2/second) -- Measure with a pyrometer, or refer to Cinquemani et al. (1978) for reported values of solar radiation. If you do not calculate solar radiation within SSTEMP, but instead rely on an external source of ground level radiation, you should assume that about 90% of the ground-level solar radiation actually enters the water. Thus, multiply the recorded solar measurements by 0.90 to get the number to be entered. If you enter a value for solar radiation, SSTEMP will ignore the dust coefficient and ground reflectivity and "override' the internal calculation of solar radiation, graying out the unused input boxes.
[NOTE: Solar radiation data are found at the NREL Solar Radiation Data Base web site (rredc.nrel.gov/solar/pubs/NSRDB).]

SHADE PARAMETER

Total Shade (percent) -- This parameter refers to how much of the segment is shaded by vegetation, cliffs, etc. If 10% of the water surface is shaded through the day, enter 10. As a shortcut, you may think of the shade factor as being the percent of water surface shaded at noon on a sunny day. In actuality however, shade represents the percent of the incoming solar radiation that does not reach the water. If you enter a value for total shade, the optional shading parameters are ignored.
[NOTE: There is a set of Optional Shading Parameters that can also be used to calculate Total Shade in SSTEMP. In 2002, Optional Shading Parameters and concurrent densiometer readings were measured at seventeen Upper Chama stations in order to compared modeling results from the use of these more extensive data sets to modeling results using densiometer readings as an estimate of Total Shade. The estimated value for Total Shade was within 15% of the calculated value in all cases. Estimated values for Maximum Temperatures differed by less than 0.5% in all cases. The Optional Shading Parameters are dependent on the exact vegetation at each cross section, thus requiring multiple cross sections to determine an accurate estimate for vegetation at a reach scale. Densiometer readings are less variable and less inclined to measurement error in the field. Therefore, densiometer readings are used to determine Total Shade for each modeled reach. Aerial photos are also examined and considered whenever available.]

OUTPUT

The program will predict the minimum, mean, and maximum daily water temperature for the set of parameters you provide (Figure 5.1). The theoretical basis for the model is strongest for the mean daily temperature. The maximum is largely an estimate and likely to vary widely with the maximum daily air temperature. The minimum is computed by subtracting the difference between maximum and mean from the mean; but the minimum is always positive. Other output includes the intermediate parameters average width, average depth and slope, maximum daily air temperature (all calculated from the input parameters), and the mean daily heat flux components.

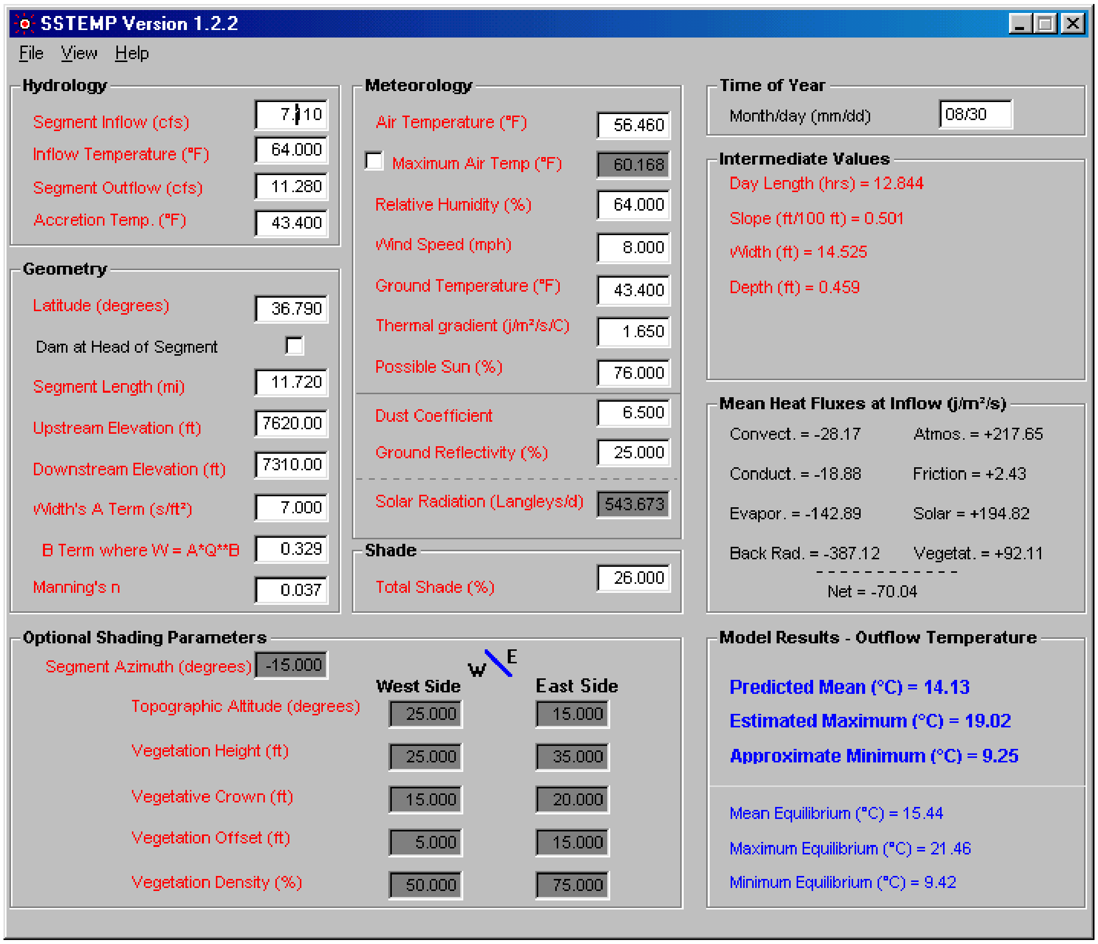


Figure 5.1 Example of SSTEMP input and output for Rio Chama.

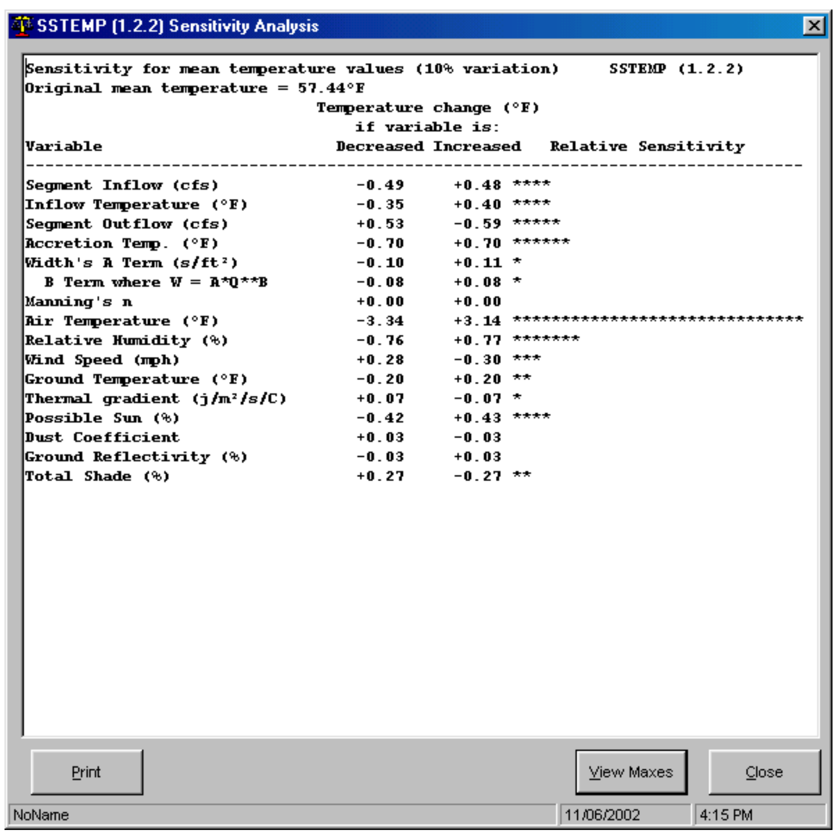
The mean heat flux components are abbreviated as follows:

Convect. = convection component
Conduct. = conduction component
Evapor. = evaporation component
Back Rad. = water's back radiation component
Atmos. = atmospheric radiation component
Friction = friction component
Solar = solar radiation component
Vegetat. = vegetative and topographic radiation component
Net = sum of all the above flux values

The sign of these flux components indicates whether or not heat is entering (+) or exiting (-) the water. The units are in joules/meter^2/second. In essence, these flux components are the best indicator of the relative importance of the driving forces in heating and cooling the water from inflow to outflow. SSTEMP produces two sets of values, one based on the inflow to the segment and one based on the outflow. The user may toggle from one to the other by double clicking on the frame containing the values. In doing so, you will find that the first four flux values change as a function of water temperature which varies along the segment. In contrast, the last four flux values do not change because they are not a function of water temperature but of constant air temperature and channel attributes. For a more complete discussion of heat flux, please refer to Theurer et al. (1984).

SENSITIVITY ANALYSIS

SSTEMP may be used to compute a one-at-a-time sensitivity of a set of input values (Figure 5.2). Use View|Sensitivity Analysis or the scale toolbar button to initiate the computation. This simply increases and decreases most active input (i.e., non-grayed out values) by 10% and displays a screen for changes to mean and maximum temperatures. The schematic graph that accompanies the display gives an indication of which variables most strongly influence the results. This version does not compute any interactions between input values.


SSTEMP (1.2.2) Sensitivity Analysis

Sensitivity for mean temperature values (10% variation)   SSTEMP (1.2.2)
Original mean temperature = 57.44°F

Variable	Temperature change (°F) if variable is: Decreased	Increased	Relative Sensitivity
Segment Inflow (cfs)	-0.49	+0.48	****
Inflow Temperature (°F)	-0.35	+0.40	****
Segment Outflow (cfs)	+0.53	-0.59	*****
Accretion Temp. (°F)	-0.70	+0.70	******
Width's A Term (s/ft²)	-0.10	+0.11	*
B Term where W = A*Q**B	-0.08	+0.08	*
Manning's n	+0.00	+0.00	
Air Temperature (°F)	-3.34	+3.14	*******************************
Relative Humidity (%)	-0.76	+0.77	*******
Wind Speed (mph)	+0.28	-0.30	***
Ground Temperature (°F)	-0.20	+0.20	**
Thermal gradient (j/m²/s/C)	+0.07	-0.07	*
Possible Sun (%)	-0.42	+0.43	****
Dust Coefficient	+0.03	-0.03	
Ground Reflectivity (%)	-0.03	+0.03	
Total Shade (%)	+0.27	-0.27	**

Figure 5.2 Example of SSTEMP sensitivity analysis for Rio Chama

UNCERTAINTY ANALYSIS

Previous versions of SSTEMP were deterministic; you supplied the "most likely" estimate of input variables and the model predicted the "most likely" thermal response. But choosing this "most likely" approach is like putting on blinders. There is variability in the natural system and inherent inaccuracy in the model. The previous model did not reflect variance in measured or estimated input variables (e.g., air temperature, streamflow, stream width) or parameter values (e.g., Bowen ratio, specific gravity of water); therefore they could not be used to estimate the uncertainty in the predicted temperatures. This version (2.0) adds an uncertainty feature that may be useful in estimating uncertainty in the water temperature estimates, given certain caveats.

The built-in uncertainty routine uses Monte Carlo analysis, a technique that gets its name from the seventeenth century study of the casino games of chance. The basic idea behind Monte Carlo analysis is that model input values are randomly selected from a distribution that describes the set of values composing the input. That is, instead of choosing one value for mean daily air temperature, the model is repeatedly run with several randomly selected estimates for air temperature in combination with random selections for all other relevant input values. The distribution of input values may be thought of as representing the variability in measurement and extrapolation error, estimation error, and a degree of spatial and temporal variability throughout the landscape. In other words, we may measure a single value for an input variable, but we know that our instruments are inaccurate to a degree and we also know that the values we measure might have been different if we had measured in a different location along or across the stream, or on a different day.

SSTEMP is fairly crude in its method of creating a distribution for each input variable. There are two approaches in this software: a percentage deviation and an absolute deviation. The percentage deviation is useful for variables commonly considered to be reliable only within a percentage difference. For example, USGS commonly describes stream flow as being accurate plus or minus 10%. The absolute deviation, as the name implies, allows entry of deviation values in the same units as the variable (*and always in international units*). A common example would be water temperature where we estimate our ability to measure temperature plus or minus maybe 0.2 degrees. Ultimately, SSTEMP converts all of the deviation values you enter to the percent representation before it computes a sample value in the range. No attempt is made to allow for deviations of the date, but all others are fair game, with three exceptions. First, the deviation on stream width is applied only to the A-value, not the B-term. If you want to be thorough, set the width to a constant by setting the B-term to zero. Second, if after sampling, the upstream elevation is lower than the downstream elevation, the upstream elevation is adjusted to be slightly above the downstream elevation. Third, you may enter deviations only for the values being used on the main screen.

The sampled value is chosen from either 1) a uniform (rectangular) distribution plus or minus the percent deviation, or 2) a normal (bell-shaped) distribution with its mean equal to the original value and its standard deviation equal to 1.96 times the deviation so that it represents 95% of the samples drawn from that distribution. If in the process of sampling from either of these two distributions, a value is drawn that is either above or below the "legal" limits set in SSTEMP, a new value is drawn from the distribution. For example, let's assume that you had a relative humidity of 99% and a deviation of 5 percent. If you were using a uniform distribution, the sample range would be 94.05 to 103.95; but you cannot have a relative humidity greater than 100%. Rather than prune the distribution at 100%, SSTEMP resamples to avoid over-specifying 100% values. No attempt has been made to account for correlation among variables, even though we know there is some. I have found little difference in using the uniform versus normal distributions, except that the normal method produces somewhat tighter confidence intervals.

SSTEMP's random sampling is used to estimate the average temperature response, both for mean daily and maximum daily temperature, and to estimate the entire dispersion in predicted temperatures. You tell the program how many *trials* to run (minimum of 11) and how many *samples* per trial (minimum of two). Although it would be satisfactory to simply run many individual samples, the advantage to this trial-sample method is twofold. First, by computing the average of the trial means, it allows a better, tighter estimate of that mean value. This is analogous to performing numerous "experiments" each with the same number of data points used for calibration. Each "experiment" produces an estimate of the mean. Second, one can gain insight as to the narrowness of the confidence interval around the mean depending on how many samples there are per trial. This is analogous to knowing how many data points you have to calibrate the model with and the influence of that. For example, if you have only a few days' worth of measurements, your confidence interval will be far broader than if you had several months' worth of daily values. But this technique does little to reduce the overall spread of the resulting predicted temperatures.

The deviations you control are arranged along the left side of the dialog box. The program uses default values that are meant to be representative of real-world values, but as always you need to scrutinize all of them for appropriateness for your situation. Grayed out items were unused on the main screen and therefore cannot be used on this screen. Display type, distribution type, number of trials and number of samples are on the top right. You may toggle the display between percent and absolute as often as you choose. Once satisfied with your values, pressing *Run* initiates the simulations. You can watch the variables change during the simulations on the main screen behind this dialog if you wish, though you will see this happen only periodically. You will also note that the routine uses whatever units (International or English) were on the main screen as it runs. The model is run a total of Trials * Samples per Trial times, and the results collected. If need be, you may press the *Stop* button to terminate the process.

Once the analysis is complete, a summary of the temperature output appears in whatever units you had chosen on the main screen. (More information is also contained in the file UNCERTAINTY.TXT that may be found in the installation folder for SSTEMP.) The best estimate of the mean and maximum temperatures are shown; these should be nearly identical to the results from the deterministic model given on SSTEMP's main screen, but you may find that they do differ somewhat. These mean estimates are accompanied by the best estimate of their standard deviation (SD) and 95% confidence interval (1.96 * SD). These are followed by the "full" estimate of the standard deviation for the full range of model predictions. These are always considerably broader than the estimates of the mean. If you have chosen more than 10 samples per trial, you will get an exceedence table displaying the probabilities of equaling or exceeding the stated temperature. Finally, you may plot a bar graph showing the frequency of trialaverage results.

If you want to estimate the mean temperature, the 95% confidence interval is recommended. This would be 1.96 times the SD of the estimate of the mean, 0.34°F in the above example. If you want to estimate the variability in the full model predictions, use 1.96 times the full distribution value, 1.21°F in the above example. As you can see, these two estimates can be widely different, though this depends on the number of trials and samples per trial. Remember that there is no magic in these statistics; they simply characterize the distributions of the data. The graphs may be more understandable to those who like figures rather than numbers, and do a good job of illustrating any skewness.

Huge data collection efforts might provide more accurate estimates for each of our input variables, but we rarely have the money to do this. We could always rely on "worst case" estimates for the input variables, where worst case is defined as that set of estimates producing the highest predicted temperatures. The probability of the worst case is too low to be practical. It is better simply to understand and acknowledge the uncertainty, but continue to make decisions based on our best estimate of the average predictions with 95% confidence intervals given.

ASSUMPTIONS

a. Water in the system is instantaneously and thoroughly mixed at all times. Thus there is no lateral temperature distribution across the stream channel, nor is there any vertical gradient in pools.

b. All stream geometry (e.g., slope, shade, friction coefficient) is characterized by mean conditions. This applies to the full travel distance upstream to solar noon, unless there is a dam at the upstream end.

c. Distribution of lateral inflow is uniformly apportioned throughout the segment length.

d. Solar radiation and the other meteorological and hydrological parameters are 24-hour means. You may lean away from them for an extreme case analysis, but you risk violating some of the principles involved. For example, you may alter the relative humidity to be more representative of the early morning hours. If you do, the mean water temperature may better approximate the early morning temperature, but the maximum and minimum temperatures would be meaningless.

e. Each parameter has certain built-in upper and lower bounds to prevent outlandish input errors. These limits are not unreasonable; however, the user should look to see that what he or she types actually shows up on the screen. The screen image will always contain the values that the program is using.

f. This model does not allow either Manning's n or travel time to vary as a function of flow.

g. The program should be considered valid only for the Northern Hemisphere below the Arctic Circle. One could theoretically "fast forward" six months for the Southern Hemisphere's shade calculations, but this has not been tested. The solar radiation calculations would, however, be invalid due to the asymmetrical elliptical nature of the earth's orbit around the sun.

h. The representative time period must be long enough for water to flow the full length of the segment. Remember that SSTEMP is a model that simulates the mean (and maximum) water temperature for some period of days. (One day is the minimum time period, and theoretically, there is no maximum, although a month is likely the upper pragmatic limit.) SSTEMP looks at the world as if all the inputs represent an average day for the time period. For this reason, SSTEMP also assumes that a parcel of water entering the top of the study segment will have the opportunity to be exposed to a full day's worth of heat flux by the time it exits the downstream end. If this is not true, the time period must be lengthened.

For example, suppose your stream has an average velocity of 0.5 meters per second and you want to simulate a 10 km segment. With 86,400 seconds in a day, that water would travel 43 km in a day's time. As this far exceeds your 10 km segment length, you can simulate a single day if you wish. But if your stream's velocity were only 0.05 mps, the water would only travel 4.3 km, so the averaging period for your simulation must be at least 3 days to allow that water to be fully influenced by the average conditions over that period. If, however, most conditions (flow, meteorology) are really relatively stable over the 3 days, you can get by with simulating a single day. Just be aware of the theoretical limitation.

i. Remember that SSTEMP does not and can not deal with cumulative effects. For example, suppose you are gaming with the riparian vegetation shade's effect on stream temperature. Mathematically adding or deleting vegetation is not the same as doing so in real life, where such vegetation may have subtle or not so subtle effects on channel width or length, air temperature, relative humidity, wind speed, and so on.

Temperature Allocations as Determined by % Total Shade and Width-to-Depth Ratios

Tables 5.1 through 5.4 detail model run outputs for Rio Chama, Chavez Creek, Rio Brazos, and Rito de Tierra Amarilla, respectively (see Appendix F for model runs). SSTEMP is first calibrated against thermograph data to determine the standard error of the model. Initial conditions are determined. As the percent Total Shade is increased and the Width's A Term is decreased, the maximum 24-hour temperature decreases until the segment specific standard of 20ºC is achieved. The calculated 24-hour Solar Radiation Component is the maximum solar load that can occur in order to meet the water quality standard (i.e., the target capacity). In order to calculate the actual Load Allocation (LA), the WLA and margin of safety (MOS) were subtracted from the target capacity (TMDL) following Equation 2.

Equation 2. $WLA + LA + MOS = TMDL$

For Rio Chama, the water quality standard for temperature is achieved when the percent total shade is 17.5% and the Width's A term is reduced to 7.0, thus simulating a decrease in the width-to-depth ratio of the channel. According to the model runs, the actual load allocation (LA) of 194.82 joules/meter2/second/day is achieved when the shade is further increased to 26% (Table 5.1).

Table 5.1 SSTEMP model results for Rio Chama

<table>
<tr><th>Rosgen Channel Type</th><th>WQS (HQCWF)</th><th>Model Run Dates</th><th>Segment Length (mi)</th><th>Solar Radiation Component per 24-Hours (+/-)</th><th>% Total Shade</th><th>Width's A Term</th><th>Modeled Temperature °C (24 hour)</th></tr>
<tr><td>B/C</td><td>20°C (68°F)</td><td>8/30/98</td><td>11.72</td><td>Current Field Condition
+233.52 joules/meter^2/second</td><td>11.3</td><td>9.14</td><td>Minimum 9.19
Mean 15.19
Maximum 21.18</td></tr>
<tr><td colspan="4" rowspan="3">Stream Segment Temperature Model (SSTEMP) Results

TEMPERATURE ALLOCATIONS
FOR
RIO CHAMA (Rio Brazos to Little Willow Creek)

* DENOTES 24-HOUR ACHIEVEMENT OF SURFACE WQS FOR TEMPERATURE

♦ DENOTES 24-HOUR LOAD ALLOCATION (LA) NEEDED TO ACHIEVE SURFACE WQS WITH A 10% MARGIN OF SAFETY

Actual reduction in solar radiation necessary to meet surface WQS for temperature:

233.52 joules/meter^2/second (current condition) – 194.82 joules/meter^2/second (LA) =

38.7 joules/meter^2/second</td><td>+205.35 joules/meter^2/second</td><td>22.0</td><td>9.14</td><td>Minimum 9.12
Mean 14.54
Maximum 19.96</td></tr>
<tr><td>*+217.20 joules/meter^2/second</td><td>17.5</td><td>7.0</td><td>Minimum 9.27
Mean 14.61
Maximum 19.96</td></tr>
<tr><td>Actual Load Allocation
♦+194.82 joules/meter^2/second</td><td>26.0</td><td>7.00</td><td>Minimum 9.25
Mean 14.13
Maximum 19.02</td></tr>
</table>

For Chavez Creek, the water quality standard for temperature is achieved when the percent total shade is 26% and the Width's A term is reduced to 8.5, thus simulating a decrease in the width-to-depth ratio of the channel. According to the model runs, the actual load allocation (LA) of 173.52 joules/meter2/second/day is achieved when the shade is further increased to 34% (Table 5.2).

Table 5.2 SSTEMP model results for Chavez Creek

<table>
<tr><th>Rosgen Channel Type</th><th>WQS (HQCWF)</th><th>Model Run Dates</th><th>Segment Length (mi)</th><th>Solar Radiation Component per 24-Hours (+/-)</th><th>% Total Shade</th><th>Width's A Term</th><th>Modeled Temperature °C (24 hour)</th></tr>
<tr><td>B</td><td>20°C (68°F)</td><td>8/30/02</td><td>12.59</td><td>Current Field Condition
+236.61 joules/meter^2/ second</td><td>10.0</td><td>16.1</td><td>Minimum 6.93
Mean 14.58
Maximum 22.22</td></tr>
<tr><td colspan="4" rowspan="3">Stream Segment Temperature Model (SSTEMP) Results

TEMPERATURE ALLOCATIONS
FOR
CHAVEZ CREEK (Rio Brazos to headwaters)

* DENOTES 24-HOUR ACHIEVEMENT OF SURFACE WQS FOR TEMPERATURE

♦ DENOTES 24-HOUR LOAD ALLOCATION (LA) NEEDED TO ACHIEVE SURFACE WQS WITH A 10% MARGIN OF SAFETY

Actual reduction in solar radiation necessary to meet surface WQS for temperature:

236.61 joules/meter^2/second (current condition) –
173.52 joules/meter^2/second (LA) =

63.1 joules/meter^2/second</td><td>+189.29 joules/meter^2/second</td><td>28.0</td><td>16.1</td><td>Minimum 6.66
Mean 13.32
Maximum 19.97</td></tr>
<tr><td>*+194.55 joules/meter^2/second</td><td>26.0</td><td>8.5</td><td>Minimum 6.02
Mean 12.99
Maximum 19.96</td></tr>
<tr><td>Actual Load Allocation
♦+173.52 joules/meter^2/second</td><td>34.0</td><td>8.5</td><td>Minimum 6.00
Mean 12.45
Maximum 18.90</td></tr>
</table>

For Rio Brazos, the water quality standard for temperature is achieved when the percent total shade is 22% and the Width's A term is reduced to 8.3, thus simulating a decrease in the width-to-depth ratio of the channel. According to the model runs, the actual load allocation (LA) of 184.89 joules/meter2/second/day is achieved when the shade is further increased to 29.8% (Table 5.3).

Table 5.3 SSTEMP model results for Rio Brazos

<table>
<tr><th>Rosgen Channel Type</th><th>WQS (HQCWF)</th><th>Model Run Dates</th><th>Segment Length (mi)</th><th>Solar Radiation Component per 24-Hours (+/-)</th><th>% Total Shade</th><th>Width's A Term</th><th>Modeled Temperature °C (24 hour)</th></tr>
<tr><td>B</td><td>20°C (68°F)</td><td>8/30/02</td><td>3.52</td><td>Current Field Condition
+223.87
joules/meter^2/
second</td><td>15.0</td><td>12.3</td><td>Minimum 8.72
Mean 14.98
Maximum 21.23</td></tr>
<tr><td colspan="4" rowspan="3">Stream Segment Temperature Model (SSTEMP) Results

TEMPERATURE ALLOCATIONS
FOR
RIO BRAZOS (Rio Chama to Chavez Creek)

* DENOTES 24-HOUR ACHIEVEMENT OF SURFACE WQS FOR TEMPERATURE

♦ DENOTES 24-HOUR LOAD ALLOCATION (LA) NEEDED TO ACHIEVE SURFACE WQS WITH A 10% MARGIN OF SAFETY

Actual reduction in solar radiation necessary to meet surface WQS for temperature:

223.87 joules/meter^2/second (current condition) –
184.89 joules/meter^2/second (LA) =

38.98 joules/meter^2/second</td><td>+190.95
joules/meter^2/second</td><td>27.5</td><td>12.3</td><td>Minimum 9.08
Mean 14.52
Maximum 19.97</td></tr>
<tr><td>*+205.43
joules/meter^2/second</td><td>22.0</td><td>8.3</td><td>Minimum 9.42
Mean 14.6
Maximum 19.96</td></tr>
<tr><td>Actual Load Allocation
♦+184.89
joules/meter^2/second</td><td>29.8</td><td>8.3</td><td>Minimum 9.52
Mean 14.38
Maximum 19.25</td></tr>
</table>

For Rito de Tierra Amarilla, the water quality standard for temperature is achieved when the percent total shade is 36%. According to the model runs, the actual load allocation (LA) of 150.85 joules/meter2/second/day is achieved when the shade is further increased to 42.5% (Table 5.4).

Table 5.4 SSTEMP model results for Rito de Tierra Amarilla

<table>
<tr><th>Rosgen Channel Type</th><th>WQS (HQCWF)</th><th>Model Run Dates</th><th>Segment Length (mi)</th><th>Solar Radiation Component per 24-Hours (+/-)</th><th>% Total Shade</th><th>Width's A Term</th><th>Modeled Temperature °C (24 hour)</th></tr>
<tr><td>E/C</td><td>20°C (68°F)</td><td>8/30/98</td><td>15.8</td><td>Current Field Condition
+248.79 joules/meter²/ second</td><td>5.0</td><td>10.8</td><td>Minimum 9.64
Mean 16.64
Maximum 23.63</td></tr>
<tr><td colspan="4" rowspan="3">Stream Segment Temperature Model (SSTEMP) Results

TEMPERATURE ALLOCATIONS
FOR
RITO DE TIERRA AMARILLA
(Rio Chama to HWY 64)

* DENOTES 24-HOUR ACHIEVEMENT OF SURFACE WQS FOR TEMPERATURE

♦ DENOTES 24-HOUR LOAD ALLOCATION (LA) NEEDED TO ACHIEVE SURFACE WQS WITH A 10% MARGIN OF SAFETY

Actual reduction in solar radiation necessary to meet surface WQS for temperature:

248.79 joules/meter²/second (current condition) –
150.85 joules/meter²/second (LA) =

97.94 joules/meter²/second</td><td>+209.51 joules/meter²/second</td><td>20</td><td>10.8</td><td>Minimum 9.28
Mean 15.6
Maximum 21.93</td></tr>
<tr><td>*+167.61 joules/meter²/second</td><td>36</td><td>10.8</td><td>Minimum 8.94
Mean 14.46
Maximum 19.98</td></tr>
<tr><td>Actual Load Allocation
♦+150.85 joules/meter²/second</td><td>42.5</td><td>10.8</td><td>Minimum 8.83
Mean 13.99
Maximum 19.15</td></tr>
</table>

According to the Sensitivity Analysis feature of the Rito de Tierra Amarilla model runs, the Width's A term was not sensitive in these model runs due to the low inflow and outflow values (< 1.5 cfs). Therefore, reducing Width's A term had an insignificant effect on the predicted maximum temperature. Rito de Tierra Amarilla flows through a broad valley from Highway 84 to the confluence with the Rio Chama. The channel through this section should be more like an E channel (small width-to-depth ratio, sinuous) (Rosgen 1996). A healthy riparian system through this portion would consist of grassy overhanging banks. To achieve a Total Shade component of 42.5% through this valley with grassy vegetation vs. woody vegetation, the channel would need to be narrower and deeper even though the model was not sensitive to the Width's A Term.

Target loads as determined by the modeling runs are summarized in Tables 5.1-5.4.
The MOS is estimated to be 10% of the target load calculated by the modeling runs. Results are presented in Table 5.5. Additional details on the MOS chosen are presented in Section 5.3 below.

Table 5.5 Calculation of TMDL for temperature

Location	WLA (J/m2/s)	LA (J/m2/s)	MOS (10%)* (J/m2/s)	TMDL (J/m2/s)
Rio Chama	0	194.82	22.38	217.20
Chavez Creek	0	173.52	21.03	194.55
Rio Brazos	0	184.89	20.54	205.43
Rito de Tierra Amarilla	0	150.85	16.76	167.61

* Actual MOS values may be slightly greater than 10% because the final MOS is back calculated after the Total Shade value is increased enough to reduce the modeled solar radiation component to a value less than the target load minus 10%.

The load reductions that would be necessary to meet the target loads were calculated to be the difference between the calculated target load allocation and the measured load (i.e., current field condition in Tables 5.1-5.4), and are shown in Table 5.6.

Table 5.6 Calculation of load reduction for temperature

Location	Load Allocation (J/m2/s)	Measured Load (J/m2/s)	Load Reduction (J/m2/s)
Rio Chama	194.82	233.52	38.70
Chavez Creek	173.52	236.61	63.09
Rio Brazos	184.89	223.87	38.98
Rito de Tierra Amarilla	150.85	248.79	97.94

Identification and Description of pollutant source(s)

Pollutant sources that could contribute to each segment are listed in Table 5.7.

Table 5.7 Pollutant source summary for Temperature

Pollutant Sources	**Magnitude** (Load Allocation + MOS)	**Location**	**Potential Sources** (% from each)
Point: None	0	--------	0%
Nonpoint: Temperature (expressed as solar radiation)		Rio Chama	100% Range Grazing -- Riparian or Upland, Removal of Riparian Vegetation Road Maintenance and Runoff Flow Regulation/Modification
		Chavez Creek	100% Range Grazing -- Riparian or Upland, Removal of Riparian Vegetation Road Maintenance and Runoff Gravel Mining Flow Regulation/Modification
		Rio Brazos	100% Unmaintained Low Water Crossing Range Grazing -- Riparian or Upland, Removal of Riparian Vegetation Road Maintenance and Runoff Gravel Mining Flow Regulation/Modification
		Rito de Tierra Amarilla	100% Range Grazing -- Riparian or Upland, Removal of Riparian Vegetation Road Maintenance and Runoff Flow Regulation/Modification Agriculture

Linkage of Water Quality and Pollutant Sources

Water temperature influences the metabolism, behavior, and mortality of fish and other aquatic organisms that affect fish. Natural temperatures of a waterbody fluctuate daily and seasonally. These natural fluctuations do not eliminate indigenous populations, but may affect existing community structure and geographical distribution of species. In fact, such temperature cycles are often necessary to induce reproductive cycles and may regulate other aspects of life history (Mount 1969). Behnke and Zarn (1976) in a discussion of temperature requirements for endangered western native trout recognized that populations cannot persist in waters where maximum temperatures consistently exceed 21-22°C, but they may survive brief daily periods of higher temperatures (25.5-26.7°C). Anthropogenic impacts can lead to modifications of these natural temperature cycles, often leading to deleterious impacts on the fishery. Such modifications may contribute to changes in geographical distribution of species and their ability to persist in the presence of introduced species. Of all the environmental factors affecting aquatic organisms in a waterbody, many either present or not present, temperature is always a factor. Heat, which is a quantitative measure of energy of molecular motion that is dependent on the mass of an object or body of water is fundamentally different that temperature, which is a measure (unrelated to mass) of energy intensity. Organisms respond to temperature, not heat.

Temperature increases, as observed in SWQB thermograph data, show temperatures along this reach that exceed the State Standards for the protection of aquatic habitat, namely the High Quality Cold Water Fishery (HQCWF) designed use. Through monitoring, and pollutant source documentation, it has been observed that the most probable cause for these temperature exceedences are due to the alteration of the stream's hydrograph, removal of riparian vegetation, and livestock grazing. Alterations can be historical or current in nature.

A variety of factors impact stream temperature (Figure 5.3). Decreased effective shade levels result from reduction of riparian vegetation. When canopy densities are compromised, thermal loading increases in response to the increase in incident solar radiation. Likewise, it is well documented that many past hydromodification activities have lead to channel widening. Wider stream channels also increase the stream surface area exposed to sunlight and heat transfer. Riparian area and channel morphology disturbances are attributed to past and to some extent current rangeland grazing practices that have resulted in reduction of riparian vegetation and streambank destabilization. These nonpoint sources of pollution primarily affect the water temperature through increased solar loading by: (1) increasing stream surface solar radiation and (2) increasing stream surface area exposed to solar radiation.

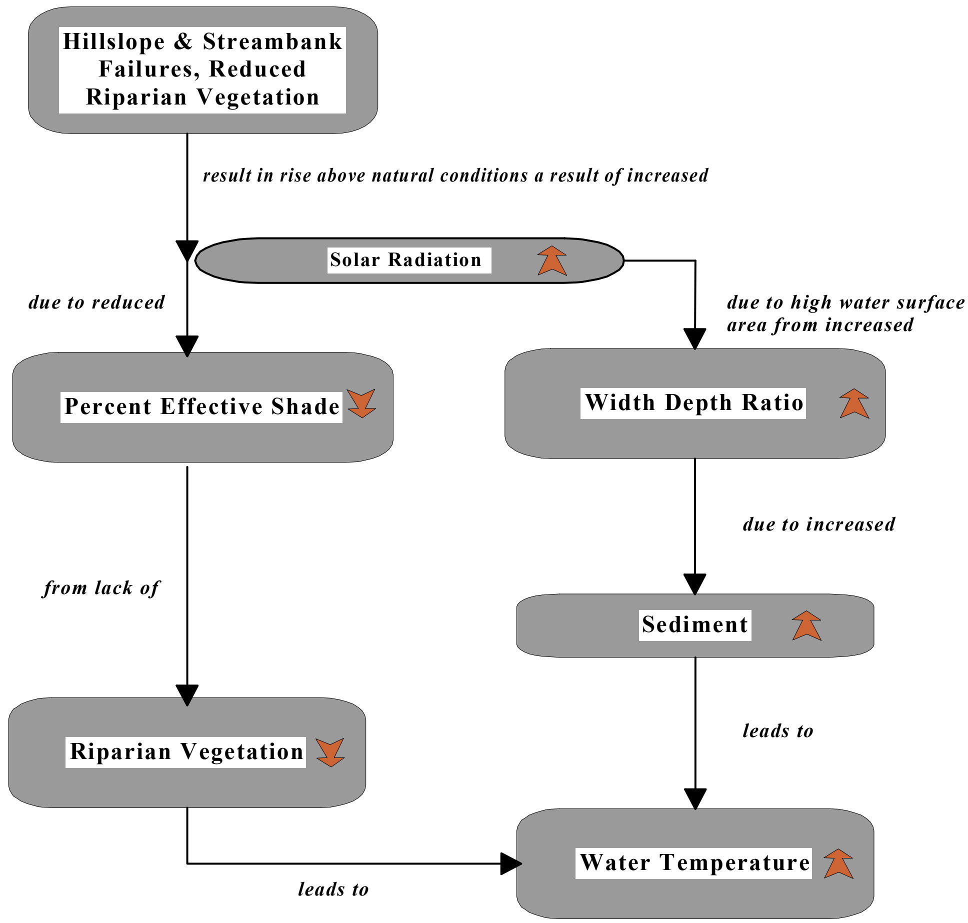


Figure 5.3 Factors That Impact Water Temperature

Riparian vegetation, stream morphology, hydrology, climate, geographic location, and aspect influence stream temperature. Although climate, geographic location, and aspect are outside of human control, the condition of the riparian area, channel morphology and hydrology can be affected by land use activities. Specifically, the elevated summertime stream temperatures attributable to anthropogenic causes in the Upper Chama watershed result from the following conditions:

1. Channel widening (i.e., increased width to depth ratios) that has increased the stream surface area exposed to incident solar radiation,
2. Riparian vegetation disturbance that has reduced stream surface shading, riparian vegetation height and density, and
3. Reduced summertime base flows that result from instream withdrawals and/or inadequate riparian vegetation. Base flows are maintained with a functioning riparian system so that loss of a functioning riparian system may lower and sometimes eliminate baseflows. Although removal of upland vegetation has been shown to increase water yield, studies show that removal of riparian vegetation along the stream channel subjects the water surface and adjacent soil surfaces to wind and solar radiation, partially offsetting the reduction in transpiration with evaporation. In losing stream reaches, increased

temperatures can result in increased streambed infiltration which can result in lower base flow (Constantz et al. 1994).

Analyses presented in these TMDLs demonstrate that defined loading capacities will ensure attainment of New Mexico water quality standards. Specifically, the relationship between shade, channel dimensions, solar radiation, and water quality attainment was demonstrated. Vegetation density increases will provide necessary shading, as well as encourage bank-building processes in severe hydrologic events.

Where available data are incomplete or where the level of uncertainty in the characterization of sources is large, the recommended approach to TMDL assignments requires the development of allocations based on estimates utilizing the best available information.

SWQB fieldwork includes an assessment of the potential sources of impairment (SWQB/NMED 1999c). The completed Pollutant Source(s) Documentation Protocol forms in Appendix C provide documentation of a visual analysis of probable sources along an impaired reach. Although this procedure is subjective, SWQB feels that it provides the best available information for the identification of potential sources of impairment in this watershed. Table 5.7 (Pollutant Source Summary) identifies and quantifies potential sources of nonpoint source impairments along each reach as determined by field reconnaissance and assessment. It is important to consider not only the land directly adjacent to the stream, which is predominantly privately held, but also to consider upland and upstream areas in a more holistic watershed approach to implementing this TMDL.

RIO CHAMA -- There is a large instream diversion structure in the Rio Chama near the NMDGF access area (SWQB station 10) that is diverting a large percentage of the flow into an irrigation canal (Photo 09). Reduced baseflows impact riparian vegetation, reduce the depth of the water, and therefore, increase solar gain. There are also areas where riparian vegetation has been altered, thus reducing the amount of total shade on the stream (Photo 10).

Photo 09. Instream withdrawal for irrigation on Rio Chama near the NMDGF access station, 10/02/02.

Photo 10. Densiometer reading on Rio Chama near the NMDGF access station, 06/24/02. Note lack of stream shading and widened channel without pool features.

CHAVEZ CREEK -- Approximately 200 meters downstream of the bridge, upstream of the confluence with the Rio Brazos, a large portion of the flow in Chavez Creek is diverted into an irrigation canal. The riparian area immediately upstream of this sampling location is heavily grazed by livestock (Photo 11). At the time of the 1998 survey, illegal dredge and fill operations were observed on Chavez Creek in this same area. A large gravel mining operation is active on the Rio Brazos upstream of and adjacent to Chavez Creek. Several of the cottonwoods in the Chavez Creek riparian area near the gravel operation are dead and/or dying. The gravel operation may be contributing to this problem by lowering the local water table. According to an aerial photograph taken in 1997, there is an approximately one mile long section of Chavez Creek about 1.5 miles upstream of the sampling station that is completely devoid of riparian vegetation. This is a result of several years of intensive gravel mining according to SWQB survey staff.

Photo 11. Grazing impacts on Chavez Creek upstream of County RD 512 bridge, 06/10/02. Note collapsed streambanks and loss of riparian vegetation to shade the stream.

RIO BRAZOS -- Upstream of the confluence with Chavez Creek, there is an irrigation diversion that diverts a large portion of Rio Brazos water into the Park View Ditch. This ditch splits and passes by the communities of Los Ojos and Rito de Tierra Amarilla. Return flow enters the Rio Chama near La Puente. There is a large gravel mining operation on the Rio Brazos upstream of the confluence with Chavez Creek. There are additional smaller active and inactive gravel mining sites along the Rio Brazos. According to an aerial photograph taken in 1997, the Rio Brazos is braided with an increased width-to-depth ratio in several reaches between the Rio Chama and Chavez Creek (Photo 12). Riparian vegetation is sparse in these areas as well, leading to increased solar radiation. There is also a low water crossing at County Road 162 that has resulted in a wide, shallow, braided reach in this section of the stream (Photo 13).

Photo 12. Looking downstream from the HWY 84 bridge on the Rio Brazos, 06/11/02.

Photo 13. Looking towards left bank at the Rio Brazos low water crossing at County RD 331, 06/11/02.

RITO DE TIERRA AMARILLA --
There is an irrigation diversion that diverts a large portion of Rito de Tierra Amarilla. This ditch travels along the on the southwest side of the community of Tierra Amarilla. The main sources of impairment along this lower reach appear to be from livestock grazing and removal of riparian vegetation in the floodplain upstream of the lower sampling station. Agricultural practices such as grazing appear to have contributed to the removal of riparian vegetation and streambank destabilization. Field staff observed several horses and cattle while at the lower sampling station

(Photo 14). There are several small animal confinement pens, increased irrigation return flows, and poorly designed culverts at road crossings. The reach flows through Tierra Amarilla in which all the above factors are concentrated (Photo 06). When the area was first settled, creating narrow strips from the road all the way to the stream so each family's livestock would have access to a water source broke up land. In many instances, these plots have been completely cleared of vegetation that would have provided shade and filtered out sediments before reaching the stream. Direct access of livestock to the stream banks has caused streambank destabilization in many areas.

Photo 14. Upstream of the lower station on the Rito de Tierra Amarilla, 10/21/01.

5.3 Margin of Safety (MOS)

The Federal Clean Water Act (CWA) requires that each TMDL be calculated with a margin of safety (MOS). This statutory requirement that TMDLs incorporate a MOS is intended to account for uncertainty in available data or in the actual effect controls will have on loading reductions and receiving water quality. A MOS may be expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL (e.g., derivation of numeric targets, modeling assumptions or effectiveness of proposed management actions). The MOS may be implicit, utilizing conservative assumptions for calculation of the loading capacity, WLAs and LAs. The MOS may also be explicitly stated as an added separate quantity in the TMDL calculation.

For this TMDL, there will be no margin of safety for point sources since there are none.
In order to develop this temperature TMDL, the following conservative assumptions were used to parameterize the model:

- Data from the warmest time of the year were used in order to capture the seasonality of temperature exceedences.

- Critical upstream and downstream low flows were used because assimilative capacity of the stream to absorb and disperse solar heat is decreased during these flow conditions.
- Low flow was modeled using two formulas developed by the USGS. One formula (USGS 2001) is recommended when the ratio between the gaged watershed area and the ungaged watershed area is between 0.5 and 1.5. When the ratio is outside of this range, a different regression formula is used (Borland, 1970). See Appendix E for details.

As detailed in section 5.2, a variety of high quality hydrologic, geomorphologic, and meteorological data were used to parameterize the SSTEMP model. Because of the high quality of data and information that was put into this model and the continuous field monitoring data used to verify these model outputs, an explicit MOS of **10%** is assigned to this TMDL.

5.4 Consideration of seasonal variation

Section 303(d)(1) of the CWA requires TMDLs to be "established at a level necessary to implement the applicable water quality standard with seasonal variation." Both stream temperature and flow vary seasonally and from year to year. Water temperatures are coolest in winter and early spring months.

Thermograph records show that temperatures exceed State of New Mexico water quality standards in summer and early fall. Warmest stream temperatures corresponded to prolonged solar radiation exposure, warmer air temperature, and low flow conditions. These conditions occur during late summer and early fall and promote the warmest seasonal instream temperatures. It is assumed that if critical conditions are met, coverage of any potential seasonal variation will also be met.

5.5 Future Growth

Estimations of future growth are not anticipated to lead to a significant increase in stream temperature that cannot be controlled with best management practice (BMP) implementation in this watershed.